AD-A143 907 WEATHERING TRIALS AND NEW RIGIDITY TESTS ON PROTECTIVE HELMETS FOR MOTOR CYCLISTS(U) AERONAUTICAL RESEARCH LABS MELBOURNE (AUSTRALIA) S R SARRAILHE JAN 84 1/1

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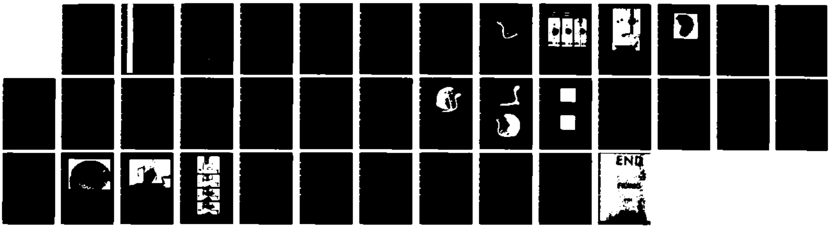

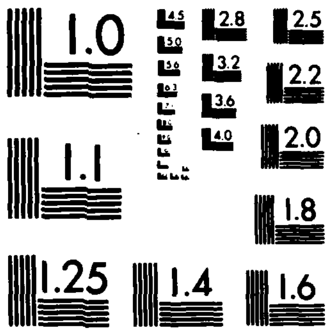

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Structures Technical Memorandum 372

WEATHERING TRIALS AND NEW RIGIDITY TESTS ON PROTECTIVE HELMETS FOR MOTOR CYCLISTS

S.R.SARRAILHE

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WEATHERING TRIALS AND NEW RIGIDITY TESTS ON PROTECTIVE HELMETS FOR MOTOR CYCLISTS

by

S.R. SARRAILHE

SUMMARY

Protective helmets with fibreglass or polycarbonate shells were exposed to the weather for three years and subjected to conventional and new rigidity tests. These indicated that:

1. Exposure did not cause deterioration in performance.
2. There was a serious imbalance between the rigidity of the shell and the hardness of the liner.
3. Some current Standards encourage selection of a grade of "shock absorbing" liner that is too hard relative to the rigidity of the shell.

Review of the standards is proposed.

POSTAL ADDRESS: Director, Aeronautical Research Laboratories, P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

CONTENTS

1. INTRODUCTION

The effect of weathering on the protective performance of crash helmets was investigated over a period of about 3 years, commencing in May 1979.

Samples of seven "brands" of helmet were exposed on the roof of the laboratories at Fishermen's Bend (which is an industrial suburb of Melbourne) and were subjected to impact tests at intervals during and/or after the three-year exposure period.

The helmet shells were constructed of fibreglass (glass fibre reinforced plastic), in one case further reinforced with polyamide fibres, or moulded in polycarbonate. These were the only shell materials available at the time that the helmets were purchased.

The impact tests were based on the standard test for resistance to penetration[1] and preliminary results have been reported previously[2,3,4].

The investigation of a fatal accident in which a polycarbonate helmet shattered[5], showed that polycarbonate shells could be embrittled by petrol or similar hydrocarbons, and that the embrittlement may not be detected by the usual tests. When embrittled helmets were tested on rigid headforms, they did not fail, but if subjected to very severe impacts, or compression tests, without the support of the solid headform they shattered, in the same way as the helmet in the accident had shattered. (Photographs of these helmets are shown in the Appendix).

The same testing procedures were applied to the weathered and stored helmets when the periodic testing had been concluded to supplement the information from the 'standard' tests.

These tests were deliberately severe in that they were intended to load the shells to the point of failure and identify any embrittlement.

2. THE HELMETS

The helmets were all "jet style" with open face fronts, as shown in Fig. 1. They were selected to represent the types in use and the sample population included expensive and low price helmets. Four "brands" had fibreglass shells and three "brands" had polycarbonate shells. One fibreglass helmet included aromatic polyamide reinforcement.

Selection did not imply endorsement or doubt regarding the performance of any brand. In this report the "brands" are identified by a number and initial letters (FG or PC) to indicate shell material.

One specimen of each "brand" was used for a survey to check the consistency of the results when a helmet was impacted at a number of points on the shell. Three specimens were exposed to the weather and three were stored, two of the exposed helmets and two of the stored

helmets were tested at intervals, the remaining helmets were retained untested, until the end of the trial, for reference. The individual helmets are identified by their "brand" identification followed by "survey", "E" for exposed, "S" for stored and '1', '2', for the regularly tested helmets, or "Ref" for the reference helmets. This notation, the principal data, and the previous reference letters[2] are given on Tables 1 and 2.

TABLE 1 - "Brand" Identification and Principal Data

Identification	Standard*	Mass gm	Size	Shell Material
1 FG	ANSI Z90 1971[6]	1200	medium	fibreglass
2 FG	Snell 75[7]	1290	medium	fibreglass
3 FC	Snell 70[8]	1362	large	fibreglass
4 FG	Snell 75	1100	medium	fibreglass and polyamide
5 PC	-	1140	-	polycarbonate
6 PC	-	1284	medium	polycarbonate
7 PC	-	1020	-	polycarbonate

* Additional standards claimed

TABLE 2 - Specimen Identification

Use of Helmet in trial	Present Notation	Previous Notation (Ref. 2)
Survey	Survey	A
Exposed reference	E Ref.	B
Stored reference	S Ref.	C
Exposed test	E 1	D
Exposed test	E 2	E
Stored test	S 1	F
Stored test	S 2	G

3. EXPOSURE AND PERIODIC TESTS

The exposure period was from May 1979 until March 1982. Impact tests were carried out on specimens "survey" E1, E2, S1 and S2, before the exposure, and on specimens E1, E2, S1 and S2 in January 1980, May 1980, January 1981 and March 1982.

At the end of each exposure period the helmets to be tested were mounted on a solid headform and impacted at two positions with a 3 kg pointed striker dropped from a height of 3 metres. The test procedure was detailed in an earlier report[2].

4. RESULTS OF PERIODIC TESTS

The striker did not penetrate to the headform in any impact (this is the acceptance criteria in the standard). The striker broke through the shells of some of the fibreglass shells, and only indented the polycarbonate shells except for one impact which produced a circular crack in the polycarbonate shell of specimen 7 PC E1, as shown in Fig. 1. This occurred after 19 months of exposure, but subsequent tests on other similar helmets did not result in cracks.

These tests did not give any other evidence of degradation in protective performance attributable to exposure.

5. NEW RIGIDITY TESTS WITHOUT A HEAD FORM

The empty helmet was supported on a flat anvil and compressed laterally by an indenter. Compressive loading was applied either slowly in a servo controlled electro-hydraulic testing machine, as shown in Fig. 2, or rapidly by a striker in a special impact facility, Fig. 3.

In either type of test the load was applied just above the "test line" (as defined in the standard). The position of the indenter on the shell is evident in Fig. 4.

The indenter had a flat contact surface 10 mm dia. and the helmet was located by pads arranged to minimise interference with the distortion of the shell.

The load transmitted through the helmet to the anvil and the deflection of the helmet at the indenter were recorded.

The compression conditions were selected to flex the shell until the opposite sides touched one another as shown on Fig. 2.

Exposed and stored helmets of each brand were subjected to both types of test.

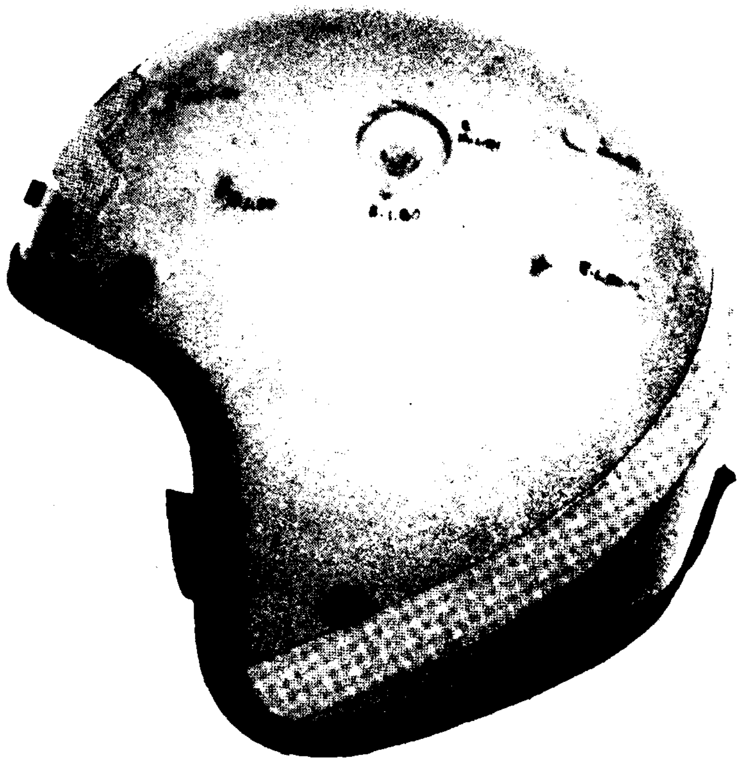

Fig. 1 - A crack in a Polycarbonate helmet (7PC E1) caused by a "penetration test" after 19 months exposure.

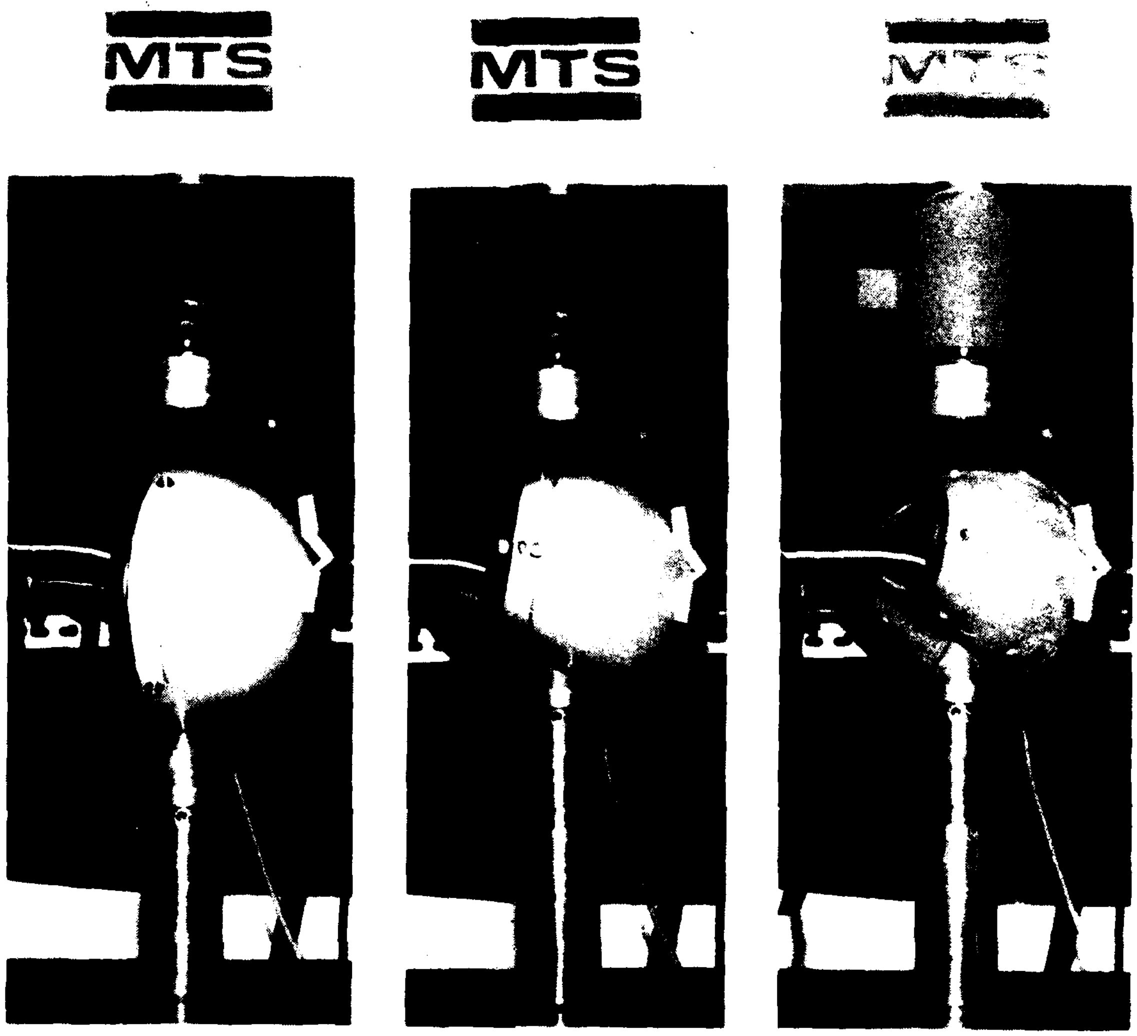

Fig. 2 - Slow compression tests
a) Fibreglass helmet unloaded (2FG S Ref)
b) Fibreglass helmet loaded 4.5kN (2FG S Ref)
c) Polycarbonate helmet loaded 3.5kN (5PC E1)

Fig. 3 - Rapid compression test rig.
(Helmet deliberately embrittled by application of solvent. Test energy 387 J)

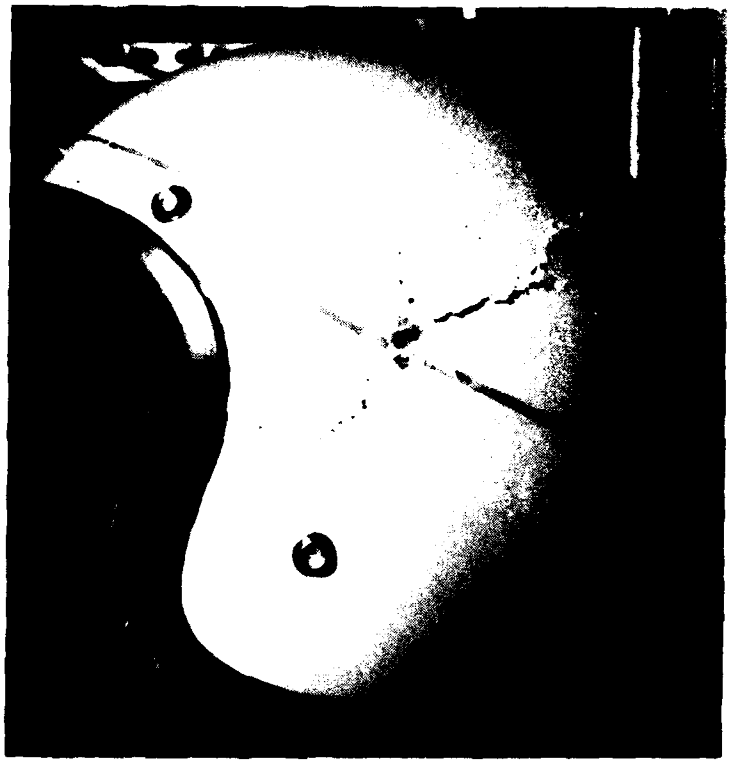

Fig. 4 - Location of the indenter (arrowed) and cracks in a fibreglass helmet after a slow compression test. The "test line" as defined in the standard[1] is drawn on the helmet.

5.1 The Slow Compression Test

The testing machine was programmed to compress the helmet 90 mm at a rate of 10 mm per second. This compression was held for 10 seconds and then reduced at 10 mm per second. The load deflection curve was plotted automatically. The energy to compress the helmet ranged from 140 to 280 joules.

5.2 Rapid Compression Test

A three kilogram striker was arranged to impact the helmet at 13 m/s. The resulting impact energy of 254 J was comparable to that in the slow compression tests, but is much greater than in any conventional approval test (e.g. the Australian Standard[1] requires an impact energy of 90 J). The test parameters were chosen to ensure destruction of the helmet so that the conditions at the point of failure, or the maximum load and deflection could be measured. To achieve the rapid impact the striker was accelerated down the rail, towards the helmet, by a rubber shock cord. The compression of the helmet was indicated by a photo-electric device which sensed the movement of the striker by detecting a series of stripes 8 mm apart on a transparent strip attached to the striker. The resulting 'blips' were displayed, together with the impact force on a storage oscilloscope. The maximum deflection was typically about 80 mm.

6. RESULTS OF THE NEW RIGIDITY TESTS

6.1 Results of the Slow Compression Tests

The polycarbonate helmets all compressed through the full 90 mm without cracking and most recovered their shape when the load was removed. When the helmets had been compressed by 40 mm the load was in the range 1.3 to 2 kN. Typical load compression curves are given in Figs. 5 to 7. All of the fibreglass shells cracked or were penetrated, but usually only when the compression exceeded 30 to 40 mm. The force at this compression ranged from 2.3 to 4.3 kN so they were considerably stiffer than the polycarbonate helmets. Load compression curves are shown in Figs. 8-11.

A typical crack in a fibreglass helmet and the position of the indenter are shown on Fig. 4.

In most cases there was little difference between the load deflection properties of the exposed and unexposed specimens. The exposed polycarbonate helmets were slightly stiffer than the stored specimens. Two of the exposed fibreglass helmets compressed at a lower load than their stored counterpart, but as they had been subjected to impacts previously and the shell cracked through the areas of previous damage, the difference in strength is probably not representative of degradation of an intact helmet.

6.2 Results of the Rapid Compression Tests

The striker compressed the polycarbonate shells 60 to 90 mm. Most recovered their shape, except for local indentation, but three exposed helmets of one brand cracked or fractured (5 PC E ref., 5 PC E1, and 5 PC E2) one example is shown in Fig. 12. These helmets had been accidentally contaminated with WD 40, a de-watering and lubricating aerosol, and this may have contributed to the embrittlement. The unexposed specimens had not been contaminated and did not crack.

Compression of the indenter into the fibreglass helmets was 50 to 70 mm, but in some cases this includes penetration of the striker into the shell, as shown in Fig. 13a and b.

Typical impact forces and 'blips' indicating compression, as recorded by the oscilloscope, are shown in Figs. 14a and b. The complex response of the shell to the impact precluded derivation of a load compression curve but by the time the deflection had reached its maximum value the load could be assessed. The maximum loads and compressions recorded in the impact tests are shown with the load compression curves (from the slow compression tests) on Figs. 5-11.

7. DISCUSSION REGARDING WEATHERING

Neither the conventional penetration test nor the more severe compression tests showed consistent evidence of reduction in performance as a result of weathering. One exposed polycarbonate helmet cracked in a conventional impact and three exposed specimens of one brand of polycarbonate helmet fractured in the high energy impact, but these had been accidentally exposed to a de-watering and lubricating aerosol and this probably affected the helmet. It is considered that attack by hydrocarbons, which can embrittle polycarbonate as shown in a previous report[5] is likely to be more serious than sunlight, or weather alone.

Regulations requiring solvent conditioning before testing are being introduced and although they will reduce risk of helmets which are unduly susceptible to solvents from being certified as "safe" they may encourage the use of other shell materials which may be more susceptible to other conditions such as UV light.

8. OBSERVATIONS ON THE RIGIDITY OF THE SHELL AND THE CRUSHING STRENGTH OF THE LINER

Shell rigidity is not usually specified in helmet standards* but the results of the compression tests may be judged against the "acceptable" impact load that is implied for the standard energy absorption test. This test effectively controls the crushing properties and the thickness of the liner because it defines the maximum permissible impact load and also the amount of energy that must be absorbed. The energy absorbed by the liner is equal to the product of the average crushing load times the depth of crush.

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* ISO Recommendation 1511[9] suggests that the shell should not deflect more than 40 mm under a load of 640 N but this is a very mild requirement and the test is not specified in the more common standards[1,6,7,8].

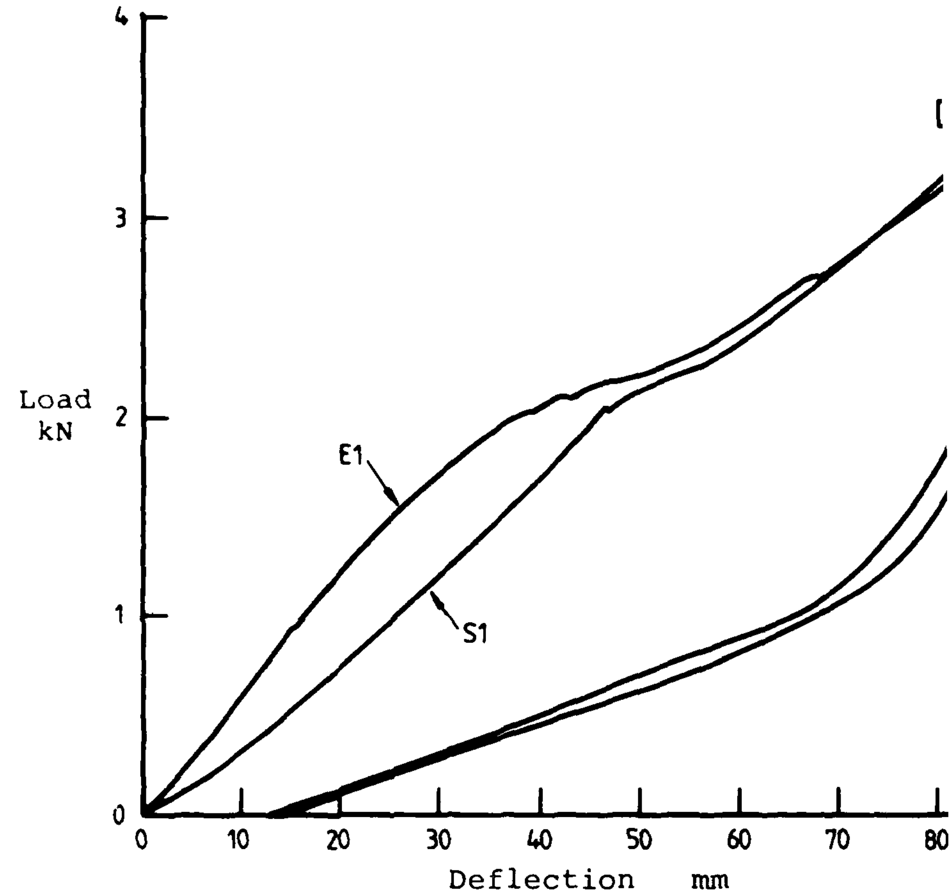


Fig. 5 - Load deflection curve for lateral compres
Polycarbonate helmets "brand" 5 PC
Curves: slow compression, helmets S1, E1
Bar: rapid compression, helmets S2, E Ref

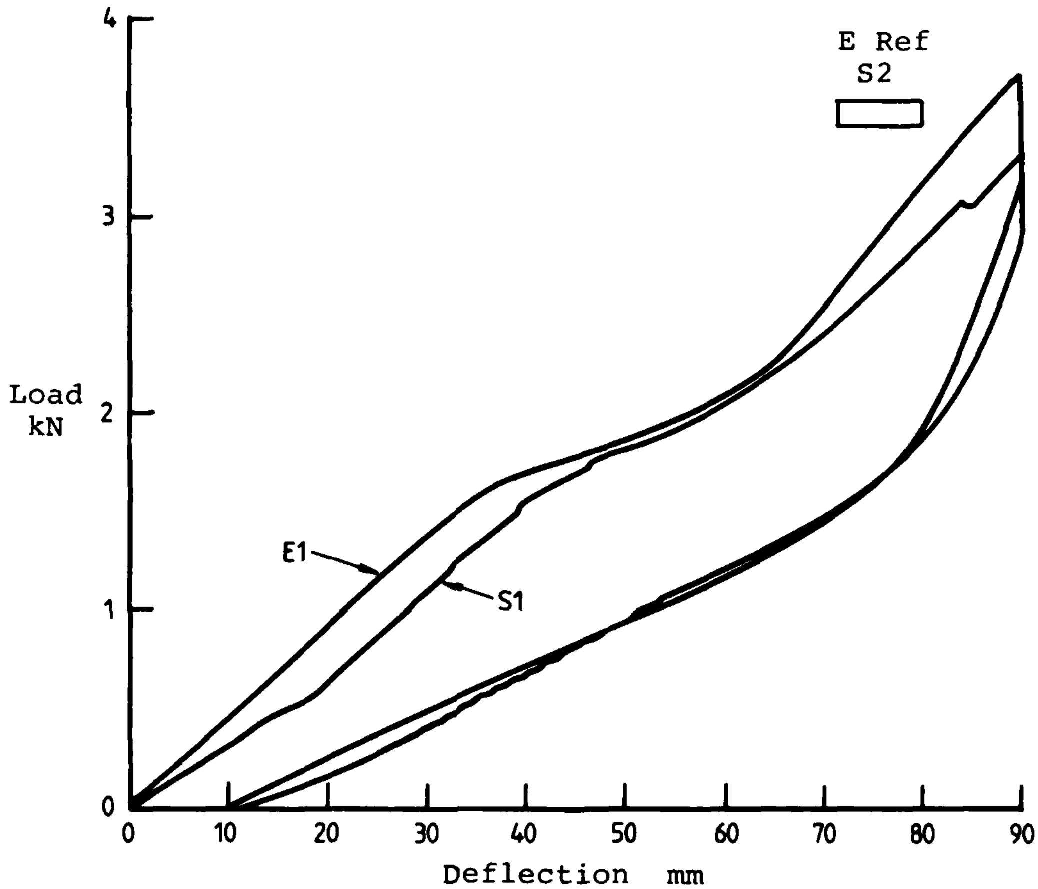


Fig. 6 - Load deflection curve for lateral compression;
Polycarbonate helmets "brand" 6 PC
Curves: slow compression, helmets S1, E1.
Bar: rapid compression, helmets S2, E Ref.

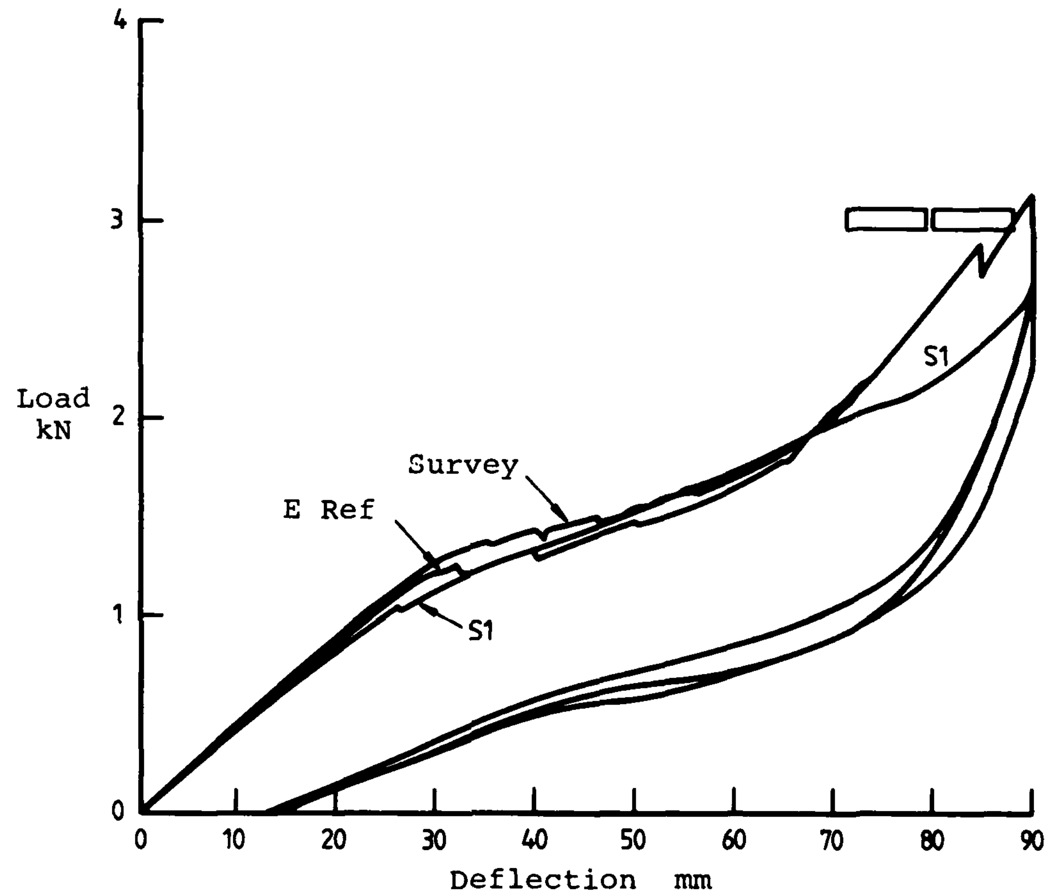


Fig. 7 - Load deflection curve for lateral compression;
Polycarbonate helmets "brand" 7 PC
Curves: slow compression, helmets Survey, S1, E Ref.
Bars: rapid compression, helmets S 2, E 2.

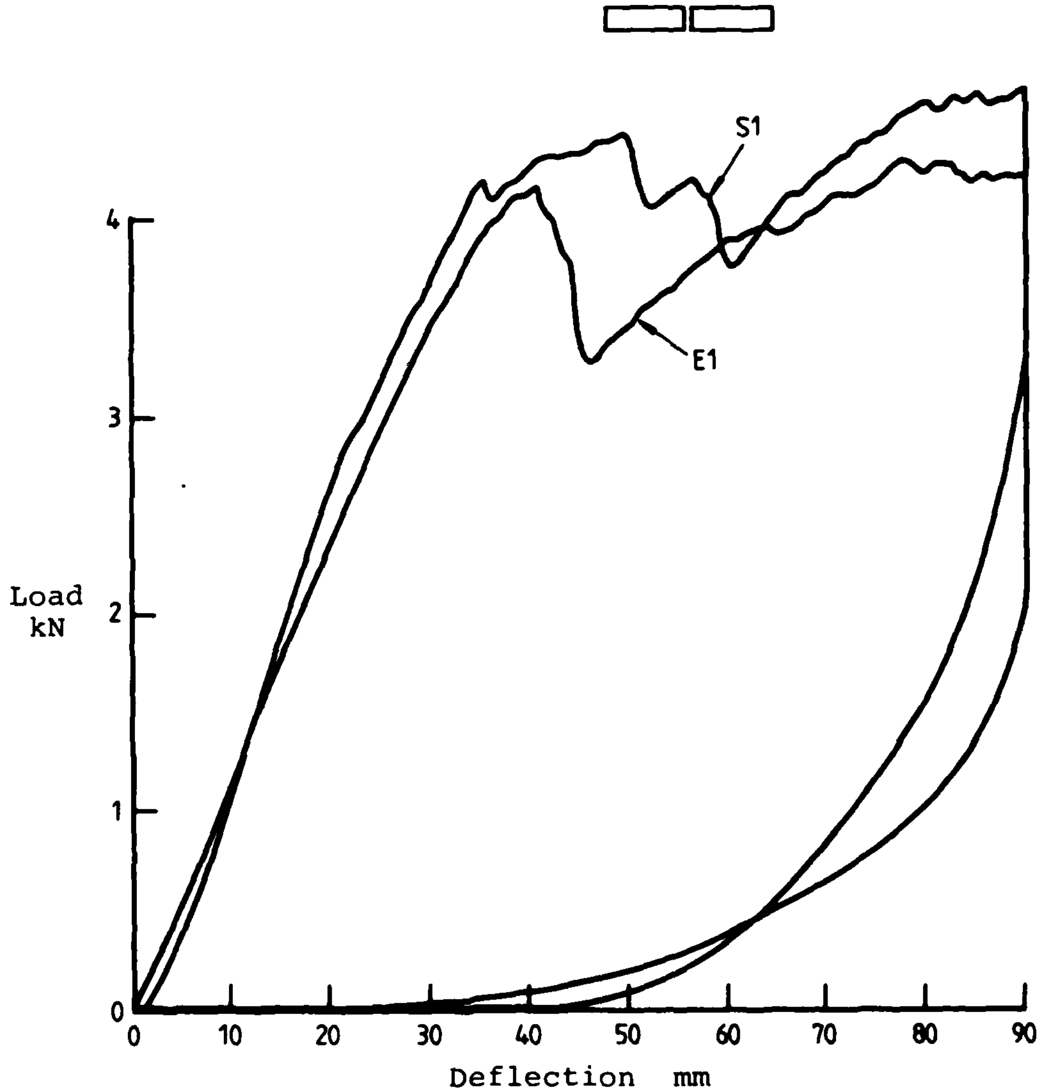


Fig. 8 - Load deflection curve for lateral compression; Fibreglass helmets "brand" 1 FG
Curves: slow compression, helmets S1, E1.
Bars: rapid compression, helmets S1, E Ref, E2.

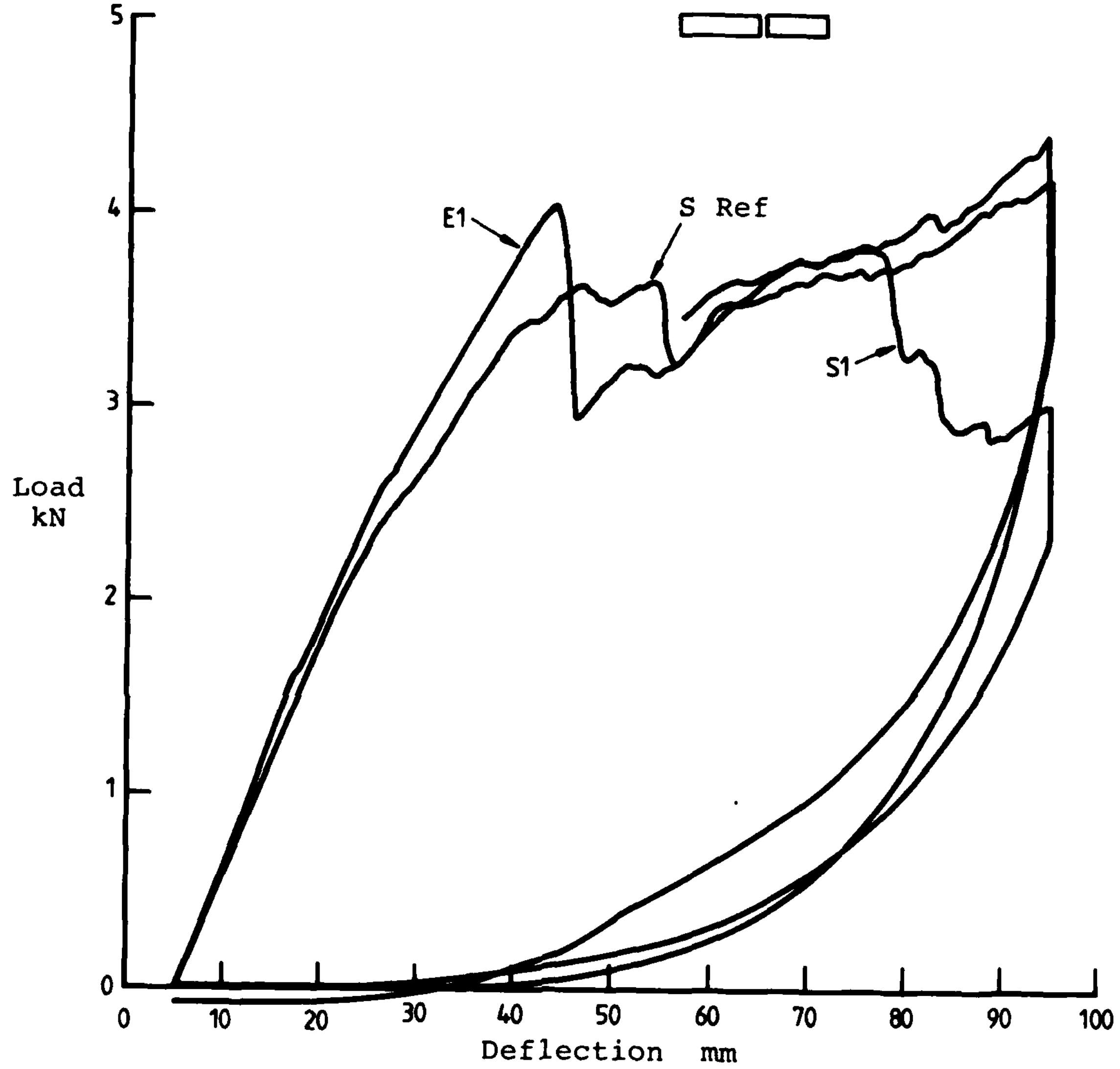


Fig. 9 - Load deflection curve for lateral compression;
Fibreglass helmets "brand" 2 FG
Curves: slow compression, helmets S Ref, S1, E1.
Bars: rapid compression, helmets S2.

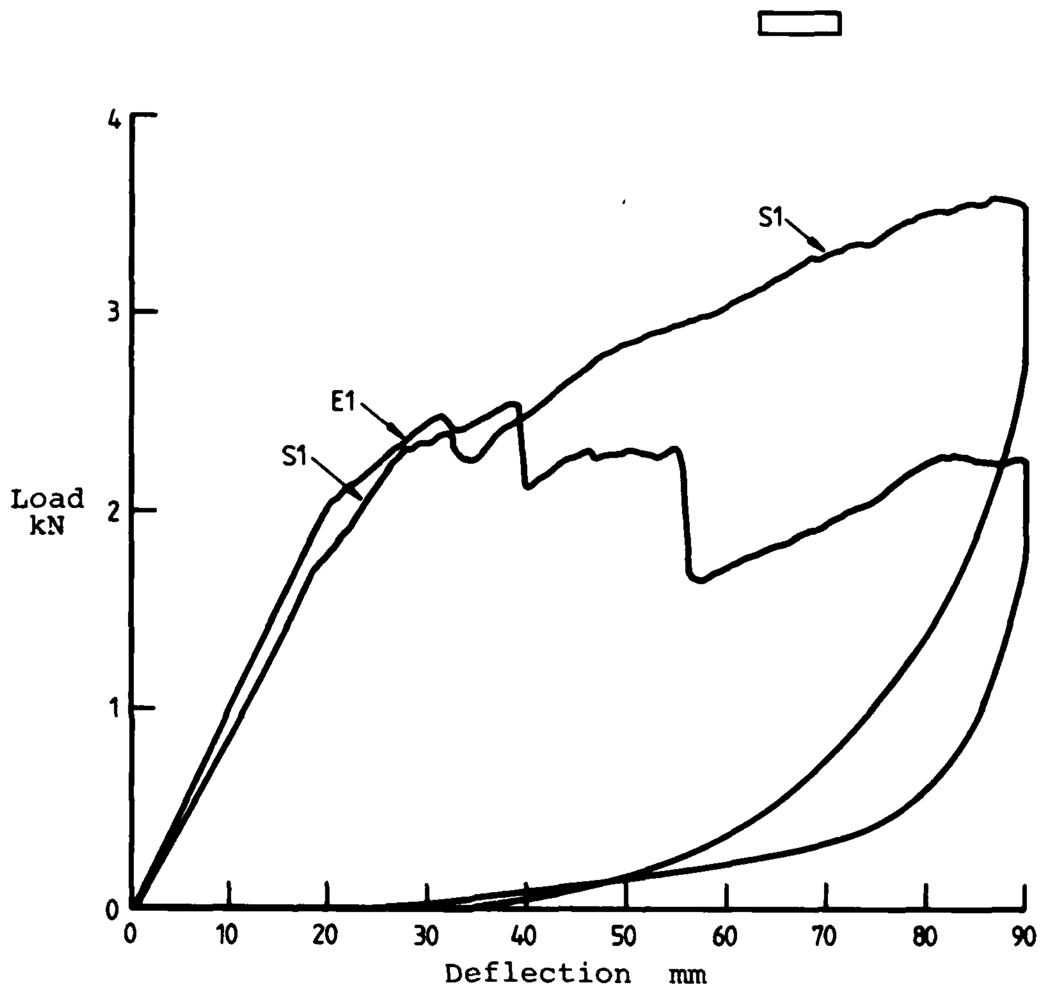


Fig. 10 - Load deflection curve for lateral compression;
Fibreglass helmets "brand" 3 FG
Curves: slow compression, helmets S1, E1.
Bar: rapid compression, helmets S2, E Ref.

(Note cracks from previous tests joined up when deflection on E1 reached 40 mm).

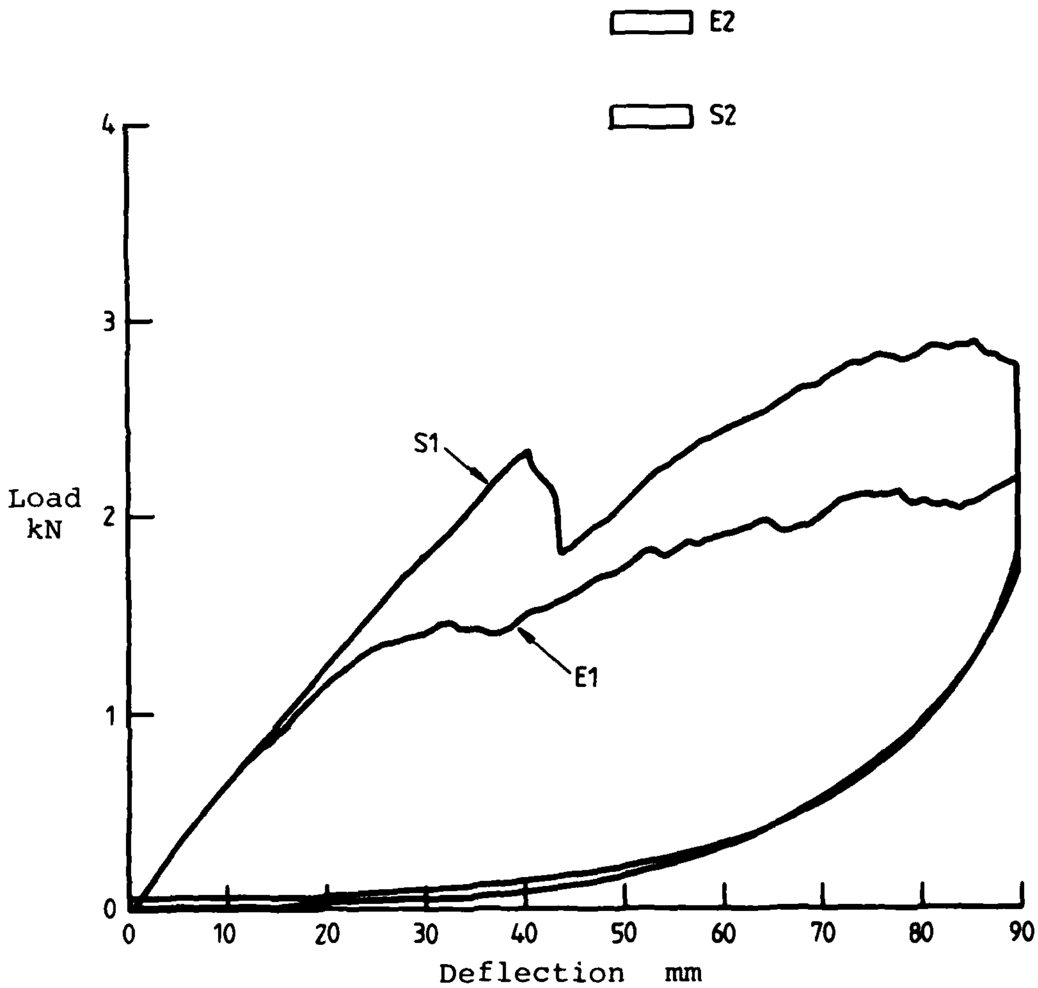
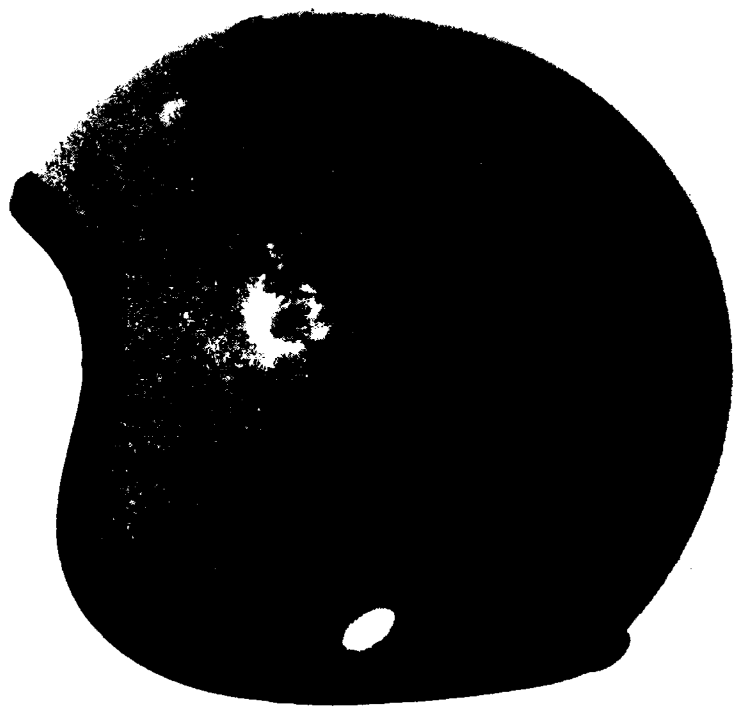


Fig. 11 - Load deflection curve for lateral compression;
Fibreglass helmets "brand" 4 FG
Curves: slow compression, helmets S1, E1.
Bars: rapid compression, helmets S2, E2.

Fig. 12 - Polycarbonate helmet which fractured in the rapid compression test.

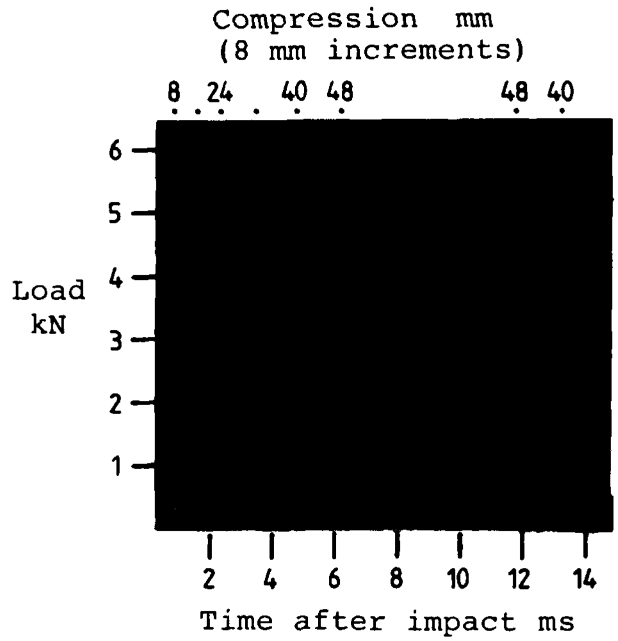
(Note this sample had been contaminated by aerosol spray).

a) Helmet 3 FG

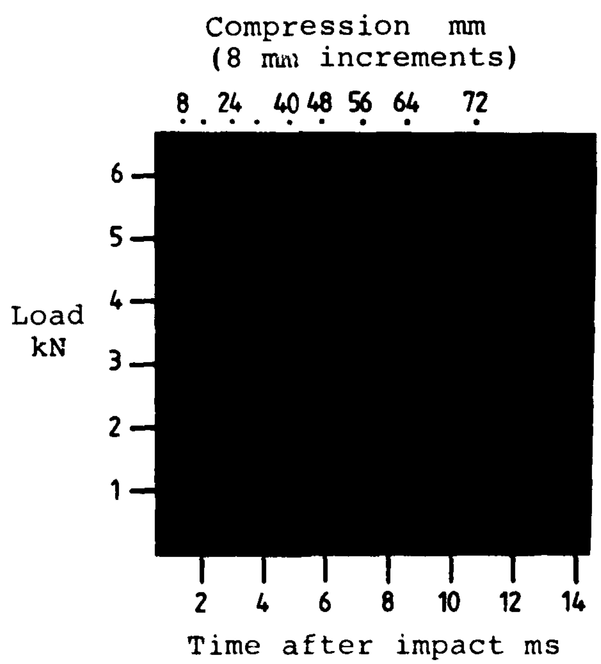


b) Helmet 1 FG

Fig. 13 - Fibreglass helmets after the rapid compression test showing deep (a) and shallow (b) indentation into the shell.



a) Helmet 1 FG



b) Helmet 6 PC

Fig. 14 - Rapid compression tests: Load shown by smooth line compression indicated by "blips", each "blip" represents 8 mm.

Typically a 5 kg headform is allowed to decelerate at 400 g[1] so the maximum permitted load is 20 kN, but the compression tests showed that, without the support of the solid headform, a force of this magnitude would produce a totally unacceptable deflection of the shell. (Helmets are shown compressed by about 4 kN on Fig. 2 and the load compression curves are shown on Figs. 5-11).

There is therefore a vast disparity between the loads that the shell can withstand and the loads effectively used to design the shock absorbing liner.

The crushing strengths of some liners were checked, but extensive measurements of the radial stiffness of the shell and liner together on a solid headform were made by Kingsbury[10] and he reported the stiffness to be as much as 1000 kN/m. This is an order of magnitude stiffer than the empty helmet shell (even if allowance is made for the difference between the "radial" measurement by Kingsbury and the "diametral" measurements made at ARL).

It may be argued that the test loading of the shell, at the two opposite sides of the helmet, was more severe than the impact of a helmeted head, when the impact loading outside is reacted by an evenly distributed inertia loading inside. However, comparison made using standard stressing formulae for similar shapes shows that the difference in the loading onto the shell is far less than the disparity between the stiffnesses of the liner and shell.

The relative stiffness of liner and shell is not detected in the standard impact test because the rigid headform allows the small area of liner under the impact point to transfer the load directly from the anvil to the headform.

In a real impact, with a less-than-solid head, the shell is likely to deflect, with possible distortion of the head, before substantial crushing of the liner can occur. This is confirmed by accident studies which indicate that although helmets are highly effective in protecting their wearers from head injury, the liner is seldom crushed to any extent. For example, Hurt[11] in a study of over 900 accidents reported that 95% of accidents had caused less than 5 mm of crush and the maximum crush was about 10 mm.

The report also showed that average liner thickness was 21 mm with a maximum of 29 mm. It would appear that there is little to be gained by the use of the thicker liners when such a small proportion of the thickness is used.

The depth of crushing in the accidents was much less than has been measured in standard tests at ARL, and this suggests that the "survivable accident" impacts were generally less severe than the standard impact tests.

A study was made by Slobodnik[12] in which accidental damage to aircrew helmets was duplicated in the laboratory and accident injury correlated with the corresponding impact deceleration measured in the test. This indicated that injury accured at decelerations, much less than 400 g and it was proposed that the maximum permitted value (for aircrew helmets) should not exceed 150 g.

It is considered that although the conventional test procedures have resulted in a highly successful protective device the protection will not be improved by increasing the energy in the impact test. Furthermore the best performance in an accident may not be achieved by optimizing the helmet to the artificial conditions of the test where a solid headform is used and the permitted deceleration is 300 to 400 g[2].

In particular, extrapolation of test parameters may be inappropriate for -

1. helmets intended to give extra protection when bulk or mass are not critical;

2. helmets for active sports where bulk and mass are critical; and

3. helmets which use new materials or methods of construction.

9. RECOMMENDATIONS

It is recommended that the basic mechanism of protection, the tolerance of a helmeted head and the relevant test procedures should be reviewed.

It is proposed that:

(1) a shell stiffness criterion be established (perhaps at a median value for current fibreglass helmets) and a test introduced into the standard;

(2) the crushing strength of the liner should be correlated to the shell rigidity; and

(3) unless and until suitable non-rigid headform can be developed impact tests should continue with a solid headform, but the permitted deceleration (or impact load) should be reduced drastically (ie. far more than the 400 to 300 g reduction that has already been made in some standards).

10. CONCLUSIONS

(1) Weathering did not have a serious effect on the performance of the fibreglass or polycarbonate helmets.

(2) Solvents such as petrol can degrade the performance of polycarbonate helmets.

(3) The standards encourage selection of a grade of "shock absorbing" liner that is too hard relative to the rigidity of the shell.

(4) Accident surveys indicate that the liner may be too hard to crush and fulfill its cushioning function in the majority of accidents.

(5) Test procedures and requirements should be reviewed and revised to introduce tests for shell rigidity. In particular the permitted impact load (or deceleration) should be reduced to increase effectiveness of the liner in accidents and restore a balance between the rigidity of the shell and the crushing strength of the liner.

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APPENDIX I

Brittle Fracture of a Crash Helmet in an Accident

A Polycarbonate helmet shattered into about when a Police Motorcyclist had a fatal accident in 1980. 1 investigations and reproduction of similar fractures at the Research Laboratories have been reported previously[5], but a of the impact region with fragments reassembled is shown or A similar helmet which fractured in laboratory tests after embrittlement with ASTM Standard fuel "C" is shown on Fig. Extracts from a high speed cine film are shown on Fig. 17. helmets only shattered in the following combination of circ

(1) after treatment with ASTM fuel "C" or petrol;

(2) when tested without a headform;

(3a) when impacted with the new rapid compression procedure involving a very high energy (384 J); and

(3b) when subjected to large deflections in the slow compre

Fig. 15 - Reassembled parts of a helmet which shattered in an accident.

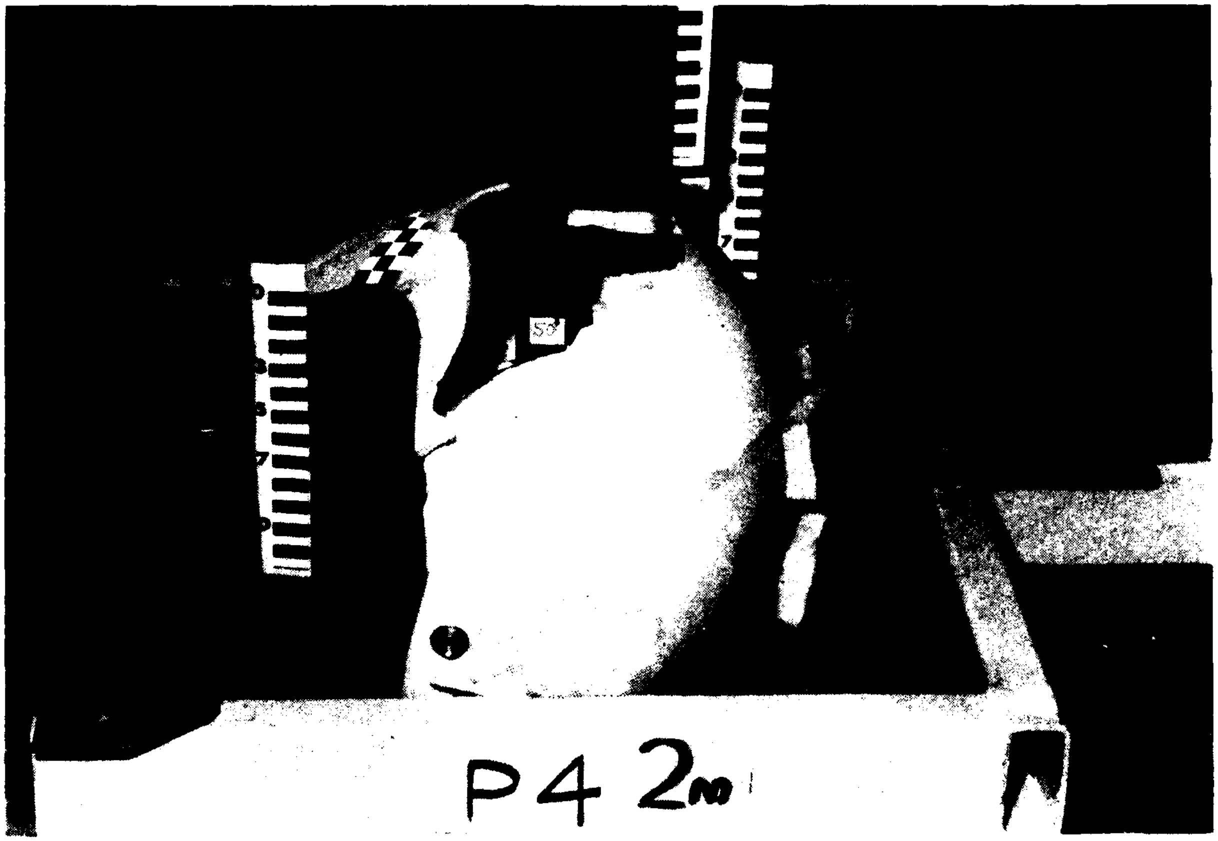

Fig. 16 - Polycarbonate helmet which fractured after treating with ASTM Standard Fuel C and impacting at 16 m/s. Energy of 384 J.

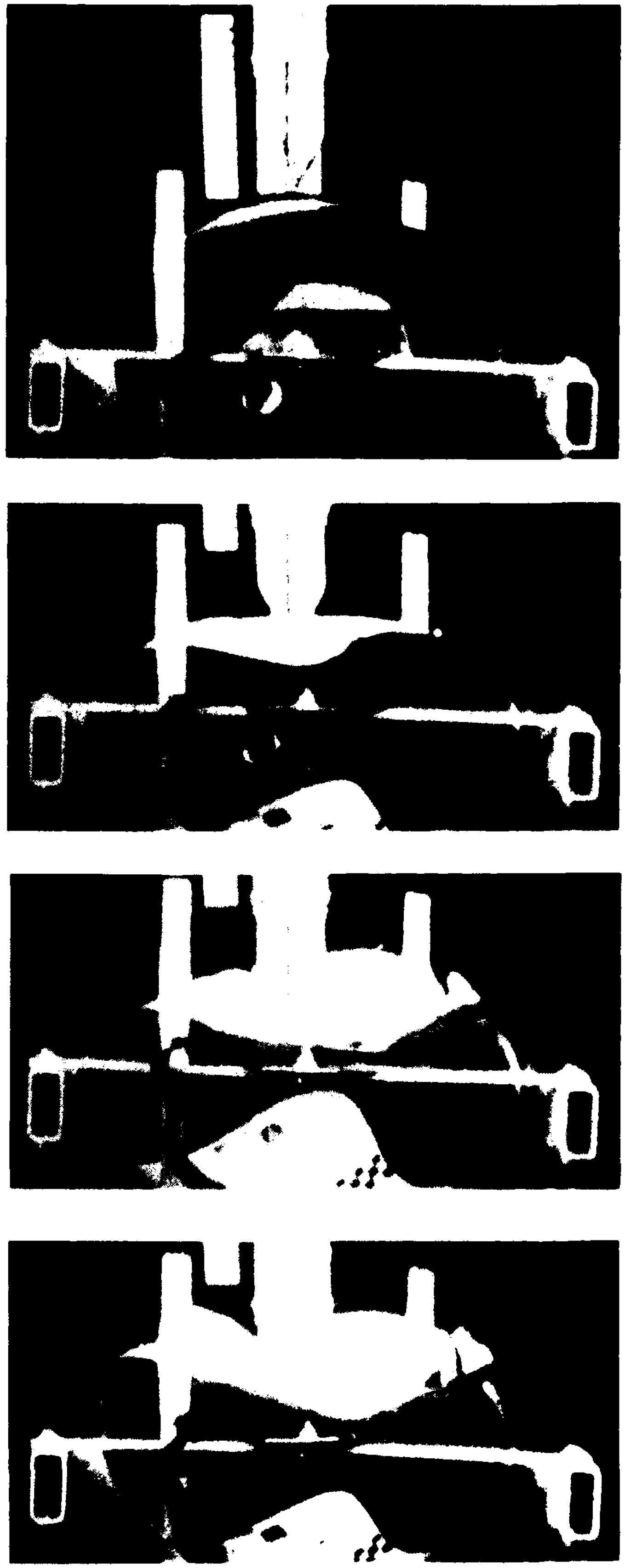

Fig. 17 - Polycarbonate helmet treated with ASTM Standard Fuel 'C' impact at 16 m/s. Photos approximately at contact and 0.005, 0.0075 and 0.01 seconds later. (from film at about 4000 frames per second)

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16. Abstract

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1. Exposure did not cause deterioration in performance.

2. There was a serious imbalance between the rigidity of the shell and the hardness of the liner.

3. Some current Standards encourage selection of a grade of "shock absorbing" liner that is too hard relative to the rigidity of the shell.

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